Express Label # EL540187599US

ANTI-GLOBAL WARMING DEVICE

Cross-Reference to Related Applications:

This application is a continuation-in-part application of U.S. Patent Application Serial No. 09/359,108 filed July 22, 1999, which is a continuation-in-part application of U.S. Patent Application Serial No. 08/933,789, filed September 19, 1997, which further claims the benefit of U.S. Provisional Application Serial No. 60/046,027 filed May 9, 1997, all of which are hereby incorporated herein by reference.

Background of Invention:

Field of the Invention

The present invention relates generally to the use of solar and thermal energy and more particularly to the radiation of thermal energy from the surface of the earth into deep space to alleviate the effects of global warming.

Prior Art

The conversion of solar energy to electrical energy through the use of photovoltaic cells is well established in the art. Photovoltaic cells are semiconductor components that convert light into useable electrical energy. A typical photovoltaic, commonly referred to as a solar cell, is comprised of an interface between an n-type semiconductor material and a p-type semiconductor material. A thin transparent layer of n-type or p-type material is deposited on a p-type or n-type material respectively to form an active p-n or n-p junction.

When the junction is exposed to visible or nearly visible light, in a solar cell application, electron hole pairs, or minority charge carriers, are created at the junction. The minority charge carriers at the n-p interface migrate across the junction in opposite directions producing an electrical potential or an electrical voltage difference. In solar cell applications electrical contacts, sometimes called ohmic contacts, are connected to the n-type and p-type materials on either side of the junction and an ensuing electric current is obtained.

The prior art has disclosed many variations of the basic p-n junction interface. Many of these variations have been attempts to improve the efficiency and effectiveness of the solar cell at absorbing solar energy. For example, a heterojunction photovoltaic device is comprised of stacked p-n junctions of different materials with band gap energies that match different parts of the solar spectrum. U.S. Pat. No. 4,332,974 discloses a multi layer photovoltaic cell wherein the first p-n layer will absorb energy in a particular band of the spectrum while the remaining energy passes through to the next p-n layer. The next subsequent p-n layer in the stack is comprised of materials that absorb a different band of the spectrum from the preceding layer. Each preceding layer acts as a window to the remaining energy of the spectrum that it does not absorb. With the cells arranged in such a fashion the amount of solar energy converted to electrical energy is expanded thus increasing the efficiency of the device.

Another example of a prior art variation of the basic p-n junction is the p-I-n junction. The p-I-n junction is comprised of p-type semiconductor material, n-type semiconductor material separated by an intrinsic-type material semiconductor material. The addition of the intrinsic-type material layer creates a diffusion potential between this

layer and the p-type material and the n-type material. The p-I-n device is constructed such that the majority of the incident light energy is absorbed in the intrinsic layer allowing more of the positive and negative charge carriers to diffuse toward their respective p-type and n-type interfaces. This variation on the basic p-n junction enhances the flow of the charge carriers and improves the overall efficiency and effectiveness of the photovoltaic cell.

Typically the individual interfaces of photovoltaic cells are interconnected to form an array or panel to supply electrical power. Regardless of the type of junction, the photovoltaic cells and the resulting arrays are subsequently interconnected in series/parallel connections to supply the required voltage and current output.

There are many cases of prior art wherein photovoltaic cells are enhanced to increase efficiency of a solar panel. For example, U.S. Pat. Nos. 4,002,499, 4,003,638, 4,088,116, 4,129,115, and 4,312,330 all disclose various methods of concentrating the incident light energy entering a photovoltaic cell. The common theme among the above cited examples is the use of a reflective device to collect sunlight distributed over a larger area and focus it upon a photovoltaic cell thereby increasing the amount of incident light energy.

The use of solar panels to convert light energy into thermal energy is also well known in the art. There are many examples of prior art which utilize light energy to passively heat fluid. For instance, U.S. Pat. No. 5,522,944 discloses the use of interconnected tubes disposed within an array of photovoltaic cells for converting solar energy to thermal energy in a fluid disposed within the tubes.

Likewise the use of a thermoelectric generator to convert thermal energy into electric energy is well known in the art. Thermoelectric generators are semiconductor or solid state devices which convert thermal energy to electrical energy directly. Unlike photovoltaic cells however they are restricted to a maximum possible thermal efficiency of $1-(T_L/T_H)$. This relationship is referred to as the Carnot efficiency and is calculated at the operating temperature between the source temperature, T_H, and the sink temperature, T_L.

Thermoelectric generators can be analyzed by using simple thermodynamic relationships at the macroscopic level unlike photovoltaic cells which normally require extensive analysis at the microscopic level. Simple fundamental relationships are utilized in the area of art to aid in understanding the function of the solid state devices employed in thermoelectric generators.

Thermoelectric generators are based on the Seebeck effect which holds that when two dissimilar materials are exposed to a temperature differential an electric current will be generated at their junction. The suitability of the materials for the thermoelectric device depends primarily on a parameter referred to as the figure of merit. The figure of merit is based on the material type evaluated at the perceived operating temperature of the thermoelectric device. The higher the value of the figure of merit in the temperature range of the thermoelectric device the better suited the materials are for a thermoelectric device. It is well known in the art to optimize the figure of merit for candidate materials by optimizing material geometries along with material types. In order to optimize the figure of merit an area ratio between the n-type and the p-type materials is selected such that the following relationships are satisfied:

$$\frac{A_n}{A_p} = [\rho_n \lambda_p / \rho_p \lambda_n]^{1/2}$$

and

$$1_n = 1_p$$

where

A_n area of n-type material
A_p area of p-type material
ρ_p, ρ_n electrical resistivity
λ_p, λ_n thermal conductivity
$1_p, 1_n$ Length of area elements.

With the semiconductor materials selected based on the above equations, the figure of merit, Z, is optimized by satisfying the following relationship:

$$Z = \frac{(| \alpha_p | + | \alpha_n |)^2}{[(\rho_n \lambda_n)^{1/2} + (\rho_p \lambda_p)^{1/2}]2}$$

where

α_p, α_n Seebeck coefficients.

For the optimum figure of merit, Z, the optimum current, I_{opt}, produced by the thermoelectric generator is calculated by the following equation:

$$I_{opt} = \frac{(| \alpha_p | + | \alpha_n |) (T_H - T_L)}{R [\chi + 1]}$$

where

$$R = \frac{\rho_n 1_n}{A_n} + \frac{\rho_p 1_p}{A_p}$$

and

T_H, T_L are the high and low temperatures of the source and the sink, respectively.

$$\chi = [\,1 + Z\,((\,T_H + T_L\,)\,/\,2)]^{1/2}$$

and

The open circuit voltage for the thermoelectric generator, $_{V_{oc}}$, is calculated by the following equation:

$$V_{oc} = (\,|\,\alpha_p\,| + |\,\alpha_n\,|\,)\,(T_H - T_L\,)$$

The specific thermal efficiency of the thermoelectric generator for the optimized conditions then becomes:

$$\eta_{th} = [1 - \frac{T_L}{T_H}] (\chi - 1) / (X + (T_L / T_H))$$

Note that it is not possible for the thermoelectric generator to have a thermal efficiency greater than the previously stated Carnot efficiency and as such T_L/T_H at the operating conditions of the device must be less than one.

An example of a thermoelectric generator is disclosed in U.S. Pat. No. 4,338,560. The thermoelectric generator of the '560 patent discloses a generator that comprises an array of sources and sinks interconnected by n-type and p-type doped material elements. It is disclosed that the sources absorb infrared heat from the earth and the sinks emit excess heat to space.

State of the art photovoltaic cells work well during daylight hours or when there is a sufficient incident light source, while thermoelectric generators tend to work better at night. What is needed is a thermoelectric-photovoltaic cell system with both enhanced terrestrial and space capabilities which employs state of the art design and manufacturing techniques to obtain maximum electrical energy output from the solar cells during daylight and sunlight conditions and from thermoelectric generator cells from temperature differentials.

The phenomenon known as "Global Warming" is an effect that some researchers feel has accelerated in the 20th century due to many of the modern conveniences that mankind has developed over the past century. This possible effect is blamed on three

main practices that occur today; the thermal dumping of energy into the environment from combustion processes such as those that take place in power plants and automobiles; a metamorphosis of thermal trapping in the way electromagnetic waves from the sun interact with our atmosphere due to these products of combustion (carbon dioxide, sulfur dioxide and nitrous oxides or CO_2, SO_2 and NO_X, respectively) that are vented into the atmosphere; and the possible depletion of the ozone layer due to interactions with chemicals that have been discharged into the atmosphere during this period. Therefore, further what is needed is a device using the principles of a thermoelectric-photovoltaic cell system to radiate thermal energy from the surface of the earth.

Summary of the Invention:

The above-discussed and other drawbacks and deficiencies of the prior art are overcome or alleviated by the subject energy generating device and method. The electricity generating device uses an electricity generating cell comprising: a first junction surface disposed in contact with a first semiconductor material; a second junction surface disposed in contact with a second semiconductor material; a third junction surface disposed in contact with the first semiconductor material and the second semiconductor material; the first and second junction surfaces disposed within a pressure cell having a pressure less than the ambient pressure; and the first and second junction surfaces at a temperature different from the third junction surface producing a thermoelectric potential between the first and second junction surfaces.

The subject disclosure also describes converting thermal radiation and sunlight into electrical energy by a method comprising: forming the device by electrically

connecting, in a parallel fashion, at least one thermoelectric cell with at least one photovoltaic cell; orienting the device such that the thermoelectric cell and the photovoltaic cell are in a perpendicular arrangement with the sunlight producing electrical energy from both the photovoltaic cell and the thermoelectric cell in the full sunlight exposure position; and producing energy from the thermoelectric cell in the full shade position.

As discussed in detail below, nighttime utilization of the invented nighttime solar cell device produces electrical energy using a thermoelectric generator (TEG) operating in the temperature differential that exists between deep space (at an effective temperature of 4°K) and the surrounding ambient temperature (nominally at 300°K). Thus, the ambient or surroundings of the device are the source of thermal energy, while deep space provides a thermal sink.

The invented nighttime solar cell includes a direct energy conversion device for producing electrical energy day and night for a terrestrial usage; the present invention simplifies the nighttime solar cell by removing the electrical generating portion of the device. In this way, the junction plate exposed to the ambient with the radiation heat transfer area still radiates to deep space. The vacuum and the entire vacuum pod are eliminated as well. Therefore, the entire junction plate is now in the ambient with the radiative surface pointed to deep space.

In its simplest operation the nighttime solar cell is provided thermal energy by the surrounding air. Thus, the ambient air is cooled as the junction plate radiates thermal energy to deep space. Obviously, the mass and magnitude of the surroundings will not be affected by the cell. But, in reality, this removes heat from the environment that the cell

occupies and radiates this heat into deep space which is at 4°K. Thus, the net effect causes an actual cooling at the surface of the earth. In reality, global warming may not even be a real condition that the earth is experiencing because there are so many other processes that are occurring in conjunction with the three effects mentioned above, that no one can say with any certainty what is really happening. For example, if we consider the effect of deep space on the overall temperature of the surface of the earth, we find some interesting results.

We know that all objects on earth have a temperature much greater than the temperature of deep space. Therefore terrestrial objects with the appropriate surface spectral properties are continuously transferring thermal energy by electromagnetic waves into deep space, a very large thermal sink. Hence there are certain objects that meet a specific criteria of surface properties, etc., which affect their ability to transmit energy through the atmosphere and into space, as will be discussed shortly.

For the transmission of thermal energy by electromagnetic radiation, the warmer the body, the more energy the body is capable of transferring. So if the temperature of the surface of the earth increases, then there will automatically be more energy transferred to deep space. We will take advantage of this phenomenon by affecting the surface and spectral properties of objects that transmit energy to deep space to ensure the maximum amount of energy is transmitted. Therefore, if global warming is a problem, which it may well be, then we can help reduce that problem significantly.

With this scenario in mind, the concept of the nighttime solar cell thermally radiating from the surface of the earth into deep space can be utilized as a means to reduce global warming, while producing electrical power. This cooling effect at the surface of

the earth (or wherever the device is located in a terrestrial setting) can still be achieved without the added benefit of electricity production. That is, the nighttime solar cell can be reduced to a single component, the cold junction plate, and be used to radiate thermal energy from the surface of the earth into deep space in a more economical, convenient, accessible way to more people.

Therefore the only portion of the nighttime solar cell needed to cool the surface of the earth is the cold junction plate radiating to deep space. The cold junction plate, called the Earth Cooler™, remains in the ambient, absorbing energy from the surrounding air, and radiates this energy away from the earth.

Consider the amount of thermal energy that can be affected at the surface of the earth. An ideal blackbody is a radiative surface that has an emissivity of one and emits energy at all wavelengths of the energy spectrum. With the assumption of a blackbody, the amount of energy that is radiated is solely a function of the temperature of the body over the energy spectrum. Therefore, a blackbody at 300°K will radiate 450 W/m^2 to a thermal sink with a temperature of 4°K. This is about one-half the energy that is available during the day at the surface of the earth due to solar energy. When there is moisture in the air, CO_2, ozone, etc., or any non-diatomic molecule (typically N_2 and O_2 are atmospheric diatomic molecules), infrared (thermal) energy will be absorbed in the atmosphere.

However, there are bands in the energy spectrum that are almost completely transparent to the movement of this radiant energy, allowing energy to travel throughout the atmosphere into deep space from the surface of the earth. This is the basic concept of the operation of the nighttime solar cell. For example, the energy spectrum between $8\mu m$

and $13\mu m$ is nearly transparent under all atmospheric conditions for radiating energy to deep space, with approximately seven other smaller bands occurring between about $0.7\mu m$ and $8.0\mu m$ as well. This represents about 40% of the total energy radiated at 300°K. Therefore upwards of 180 W/m^2 of energy can be radiated into deep space, cooling the surface of the earth. In dry, arid climates, less moisture in the air can increase the amount of energy radiated considerably.

The effectiveness of the present invention as an anti-global warming device can be put into perspective very simply. The United States consumes about 17 million barrels of crude oil a day. Considering an average conversion efficiency of 30% into useful work, 11.9 million barrels go into the ambient as waste heat. There are about 138,100 BTUs/gal of crude oil, and with the US population around 275 million, that averages to 3064 watts per person. Therefore a surface area of $50m^2$ of the present invention for each US citizen would be needed nightly for about 8 hours to completely offset the thermal effects on the ambient from the burning of oil.

Or, in another comparison, about 1810 sq. miles of the present invention would be needed for round-the-clock exposure to deep space to accomplish thermal cooling to offset the amount of crude oil used in the US today. This equals less than seven-tenths of one percent of the land area in the state of Texas. Therefore if the US government considered the effects of global warming to be catastrophic to the ecosystem of the world, arid desert land could be set aside for this purpose. If the present invention were coupled with the nighttime solar cell, electricity could be produced on this designated land.

And certainly the nuclear power industry produces thermal pollution that can be negated with array panels according to the present invention. Any industry, chemical,

automotive, power utility, steel mill, foundry, etc., that produces thermal pollution can utilize this device to offset effects of its thermal dumping into the atmosphere.

With more fossil fuel combustion, more CO_2 will be added to the atmosphere, perhaps causing a change in the spectral window for transferring energy to deep space. However, fossil fuel reserves will be depleted (including coal) well before enough CO_2 enters the atmosphere to influence the spectral window. By then a renewable energy source (such as solar converted electrical energy beamed to the surface of the earth via wireless power transmission from geosynchronous satellites) will be available. The present invention can still be utilized if necessary to dump waste thermal energy into deep space from a pollution-free energy source.

Heat or thermal energy in the form of electromagnetic energy waves is called infrared energy. Infrared waves are longer than light waves, yet shorter than radio waves. The infrared waves are also capable of traveling through certain media, yet not through others. Infrared energy cannot travel through certain window glass (typically silica, fused silica, borosilicate, etc.), yet it can travel through the atmosphere. And at particular wavelengths, none of the infrared energy is absorbed by the atmosphere so it travels right into deep space where nothing will absorb it for a long distance.

The present anti-global warming device takes advantage of this phenomenon: transmitting infrared radiant thermal energy into deep space at wavelengths that are transparent to the molecular components in the atmosphere.

The success of the anti-global warming device depends on three factors: (1) utilizing specific materials having surface properties that can transmit infrared thermal energy at wavelengths that are transparent to the atmosphere; (2) replacing existing

terrestrial surfaces that are visible to deep space with these special materials - this replacement can be as simple as placing specific materials over an existing terrestrial object or by specific redesign or retrofit of existing equipment to produce this cooling effect; and (3) using the device at night or in the shadow of a building to ensure direct insolent solar energy does not heat the cooler during the day.

The crucial link in the success of the anti-global warming device is the surface finish and/or properties that face and transmit electromagnetic energy to deep space. Ideally, we would want the surface to behave as a blackbody with an emissivity of one throughout the full spectrum range. In reality, these surfaces do not exist. However, balckbody cavities do exist and can be utilized, pursuant to the present invention, for transmitting energy into deep space.

Research has shown that spectrally selective coatings that perform best in specific spectral bands, for example in the $8\mu m$ to $13\mu m$ range, can actually emit higher radiative fluxes than a blackbody would exhibit. Therefore we would need to utilize a surface finish that approaches a blackbody radiator, or utilize materials that function best only in the spectral bands that are transparent to the atmosphere.

As discussed previously, the $8\mu m$ to $13\mu m$ band is the single largest band in the spectrum. Therefore the radiative surface property of emissivity for the material chosen should be greatest in this band. The following examples are given as typical finishes that can be used for the surface of the anti-global warming device. These are obviously used for examples only and do not mean to restrict the list in any way. There are certainly polymers, elastomers, glasses, etc., that have favorable properties for the device. Also, included are the normal spectral emissive property of the material, which is suitably one

of the best indicators for the spectral behavior of the material finish. Obviously hemispherical or total emissivity could be used as well. The materials are:

(i) carbon pigmented coating (lampblack in an epoxy binder) on a smooth substrate such as aluminum or Inconel - normal spectral emissivity = 0.94

(ii) chromium oxide (Cr_2O_3) pigmented coating on a smooth substrate - normal spectral emissivity = 0.95

(iii) Krylon flat black paint on aluminum - normal spectral emissivity = 0.96

(iv) anodized aluminum - normal spectral emissivity = 0.92

(v) clear lacquer on aluminum substrate - normal total emissivity = 0.92

(vi) iron conversion (Armco blackened steel) on smooth steel surface - normal spectral emissivity = 0.85

Note that the emissivities are not constant throughout the spectral band; average values have been chosen as examples.

Other types of radiators to deep space include polyvinyl chloride plastic (TEDLAR by Dupont) deposited as a 12.5μm thin film on an aluminum substrate; white paint containing at least 35% titanium dioxide applied on a smooth surface such as aluminum; and polyvinyl-fluoride deposited on aluminum. These would also provide adequate surface finishes for the anti-global warming device.

As a rule, typically for metals the normal spectral emissivity decreases as the wavelength increases further into the infrared range; for non-metals the normal spectral emissivity increases as the wavelength increases. Therefore, there are also polymers and elastomers and other non-metallic solid materials (presumably even liquids), aside from coatings, that can function quite well in the present invention. The list of materials and/or

finishes is quite extensive, and can be rather exotic, as shown above. In addition, new materials are being developed all the time for various uses which can also be utilized for the anti-global warming device - especially very inexpensive ones.

For example, black butyl rubber, polyvinyl chloride (white), and acrylonitrile butadiene styrene (black) have favorable spectral emissivity ranges of about 0.92 to 0.97, 0.94 to 0.96, and 0.91 to 0.96, respectively, in the infrared spectral band $3\mu m$ to $15\mu m$ (measured 10 degrees incidence from normal).

To obtain a desirable spectral surface for a transmitting material of the present invention, the material surface should be finished with a maximum spectral emissivity (as close to 1.0 as possible preferably ranging from about 0.8 to about 1.0) in the atmospheric bands (previously specified) that are transparent to infrared thermal energy. The same surface preferably should have a very low (as close to 0.0 as possible preferably ranging from about 0.3 to about 0.0) absorptivity. If the same surface is shielded from, or never sees, direct sunlight, then the low absorptivity property is not necessary.

In another embodiment of the invention, a high emissivity surface is covered with a coating that reflects incoming thermal infrared electromagnetic energy. Preferably, all bands would be reflected. Gold, silver, aluminum (oxide), Inconel, and the like are preferred reflectors, if applied as a very thin foil. However, commercial polymers as well as other metallic and optical coatings are available which would reflect incoming infrared energy, reducing energy absorption while allowing the spectral transmission of thermal energy from the substrate surface at the desired wavelengths. The reflective coating behaves similarly to a one-way mirror or even a beam splitter.

The transmitting material of the present invention also may be a high emissivity coating on a polymer or metallic substrate. For example, carbon black, acetylene soot, camphor soot, or lamp black suspended in a high transmissivity polymer or optical coating applied to an aluminum, other metal, or plastic substrate will provide a high emissivity coating. Obviously other materials could be suspended in the polymer with the desired spectral properties. The polymer or optical coating is transparent in the required spectral bands or the full spectrum as needed. This high emissivity coating additionally may have a highly reflective coating to reduce the absorptivity of the lamp black/polymer coating. In this application, again the reflective coating acts similarly to a one-way mirror where the infrared radiation leaves the surface but incoming thermal energy is reflected off the reflective coating.

Yet another embodiment of the present invention involves a spectral material (for example, zinc selenide, zinc sulfide, silver chloride, potassium chloride, and the like) suspended in a highly transmissive polymer and applied as a coating or utilized as a window. In this application, the coating or window will retain the spectral properties of the suspended material. Therefore, spectral properites can be adjusted and/or augmented to match the application requirements, and the polymer is transparent as required.

As a contrast to some of the materials and their properties presented above, the normal spectral emissivity or polished, untreated aluminum is 0.04. Therefore it is quite obvious that surface treatment and/or surface finish of the material is critical in effecting its spectral properties.

There are also transparent bands between $3\mu m$ and $4\mu m$ and between $0.7\mu m$ and $2.7\mu m$ (and others) that would be appropriate for the transmission of infrared thermal

energy into deep space. Materials could easily be chosen to radiate in this (these) band(s) as well.

The placement of the presently invented device on terrestrial surfaces will indicate the effectiveness of the new device. First the radiative surface must be facing deep space with no obstructions blocking its view. Secondly, the anti-global warming device must be placed over a surface that is not already transmitting radiant energy to deep space in spectral bands that are transparent to the atmosphere, or at least the emissivity of the device must be higher in the spectral bands than the object it is covering. For example, a 20cm x 20cm device with an emissivity of 0.92 can be placed on a fence post with an effective emissivity of 0.2 (this will be illustrated later in the figures). Ice has a normal emissivity of 0.97; therefore this anti-global warming device may not be effective if set on a frozen pond surface or over a bucket full of frozen water; spectral bands then become critical.

Utilizing the present invention in a specific redesign or retrofit of equipment will be shown and discussed in several of the figures.

Using the present invention at night or in the shadow of a building to prevent direct solar energy from striking the cooler is a feature that must be considered. Typically, radiative blackbody surfaces that are good emitters of thermal energy are also good absorbers of radiant energy. Therefore if the anti-global warming device is left in direct sunlight during the day, the device will absorb more energy than the terrestrial object it is covering, thereby adding to global warming. Hence the simple portable device should be put away until the sun goes down.

Ideally the best surface finish for the device would be a material that has a high emissivity (in the 0.92 range, or higher) in the above mentioned spectral band or bands while having a low absorptivity (in the range of 0.2 or less) in the same band(s). In this way the device could be left in the sun all day without the consequence of higher global warming by day for this particular application of the device.

The above-discussed and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the following detailed description and drawings.

Brief Description of the Drawings:

Referring now to the drawings wherein like elements are numbered alike in the several Figures:

Figure 1 is a schematic representation of a thermoelectric-photovoltaic cell of the present invention.

Figure 2 is a schematic representation of a thermoelectric-photovoltaic cell of the present invention.

Figure 3 is a cross sectional view of a thermoelectric-photovoltaic cell of the present invention.

Figure 4 is a cross sectional view of a thermoelectric-photovoltaic cell of the present invention.

Figure 5 is a cross sectional view of an array incorporating a thermoelectric-photovoltaic cell of the present invention.

Figure 6 is a plan view of an array panel and support structure incorporating a thermoelectric-photovoltaic cell of the present invention.

Figure 7 is a cross sectional view of an array panel and support structure incorporating a thermoelectric-photovoltaic cell of the present invention.

Figure 8 is a perspective illustration of a satellite incorporating a thermoelectric-photovoltaic cell of the present invention.

Figure 9 is a cross sectional view of a thermoelectric-photovoltaic cell of the present invention.

Figure 10 is a cross sectional view of a thermoelectric-photovoltaic cell of the present invention.

Figure 11 is a cross sectional view of a thermoelectric-photovoltaic cell of the present invention.

Figure 12 is a cross sectional view of a thermoelectric generator of the present invention where the junction surface area is varied to improve performance.

Figure 13 is an isometric view of a thermoelectric-photovoltaic cell of the present invention where the radiative area is varied as well as the size of the various p-type and n-type materials.

Figure 14 is a cross sectional view of a cascading thermoelectric generator of the present invention.

Figure 14A a cross sectional view of a cascading thermoelectric generator of the present invention.

Figure 15 is a cross sectional view of a thermoelectric generator of the present invention where the geometry and size of the p-type and n-type materials are adjusted to increase thermal resistance and improve power output.

Figure 16 is a cross sectional view of a thermoelectric generator of the present invention which employs metallic conductors to enable an increase in the length of the p-type and n-type materials.

Figure 16A is a cross sectional view of section AA from Figure 16 which illustrates the orientation of the p-type materials with respect to the n-type materials.

Figure 16B a cross sectional view of a thermoelectric generator of the present invention which illustrates another orientation scheme using a p-type/n-type material arrangement as in Figure 16A.

Figure 17 is a cross sectional view of a thermoelectric generator of the present invention employing another geometry which snakes the p-type and n-type materials to increase their length.

Figure 18 is a cross sectional view of a thermoelectric generator of the present invention employing thin film insulators to enable condensed snaking of the p-type and n-type materials to optimize usage of space.

Figure 19 is an isometric view of an array incorporating cells of the present invention where the cells are in individual reduced pressure units arranged in an array.

Figure 20 is a cross sectional view of a thermoelectric-photovoltaic cell of the present invention which illustrates daytime and nighttime operation of the cell.

Figure 21 is a cross sectional view of a cell of the present invention which employs both internal and external heat transfer augmentation.

Figure 22 is a cross sectional view of a cell of the present invention employing alternate internal heat transfer augmentation.

Figure 23 is a cross sectional view of a cold junction plate serving as a direct link between ambient surroundings and deep space.

Figure 24 is a cross sectional view of a cold junction plate without an optional vacuum cell.

Figure 25 is an isometric view illustrating the present invention in a simple embodiment.

Figure 26 is an isometric view of the present device with support feet.

Figure 27 is an isometric view of an embodiment of the present invention including heat transfer fins.

Figure 28 is a perspective view of an automobile utilizing an embodiment of the present invention.

Figure 29 is a perspective view of an automobile utilizing an embodiment of the present invention.

Figure 30 is a perspective view of a building employing an embodiment of the present invention.

Figure 31 is a perspective view of a mortar boards application of the present invention.

Figure 32 is a perspective view of a section of fencing using the present invention.

Figure 33 is a perspective view of a Frisbee-type disc employing the present invention.

Figure 34 is a perspective view of an outdoor light using the present invention.

Detailed Description of the Preferred Embodiments:

An embodiment of the nighttime solar cell of the present invention is shown schematically in Figure 1. The nighttime solar cell 1 of the present invention includes a thermoelectric generator 10, current flow circuitry 20, and a current load 21. The generator is comprised of a junction surface 11, a junction surface 12, a reduced pressure cell 13, n-type doped material 14, and p-type doped material 15. The schematic presented in Figure 1 depicts the operation of the present invention in a nighttime terrestrial embodiment. The junction surface 11 emits thermal energy through radiation heat transfer 16 to the black sky at night. In this embodiment junction surface 11 becomes a cold temperature sink for the thermoelectric generator 10 preferably having an emissivity greater than 0.90, with about 0.96 to about 0.99 especially preferred. The black sky has an effective temperature around zero degrees absolute temperature which allows the cold temperature sink to radiate heat to the black sky via electromagnetic energy. In a terrestrial embodiment of the present invention the junction surface 12 is the hot temperature source as it is exposed to ambient temperature, typically about 200°K to 325°K, with about 220°K to 310°K more common. The temperature difference that exists between the junction surfaces produces an electrical current 17 in the p-type material and the n-type material of the thermoelectric generator.

The present invention utilizes reduced pressure cell 13, 13', 13″ (see Figures 9, 10, and 11) to take advantage of the extremely low temperatures of the black sky. The reduced pressure cell can encapsulate the junction surface 11, encapsulate the thermoelectric generator 10 except for junction surface 12, or can encapsulate the entire thermoelectric generator, to insulate the junction surface 11 or the thermoelectric generator 10 from the ambient temperatures. The pressure within the reduced pressure cell 13 is a pressure lower

than the ambient pressure, with the ideal pressure of the reduced pressure cell 13 being a perfect vacuum. The reduced pressure cell 13 is manufactured from a material suitable to allow junction surfaces 11 to "see" the black sky and exchange energy with it by radiation heat transfer.

In one embodiment, referring to Figures 9 and 10, the reduced pressure cell 13' (also known as the vacuum cell or vacuum pod), encapsulates the photovoltaic cell 30 and the majority of the thermoelectric generator 10, leaving junction surface 12 thermally connected to the environment and allowing the establishment of heat transfer with the surroundings. Utilizing the reduced pressure cell 13' in this fashion enables the elimination of the insulation 40 (see Figures 3 and 4), thereby reducing the overall system weight and cost, while providing a more effective insulation of the photovoltaic cells and allowing the thermoelectric generator to operate at a higher daytime temperature to improve its performance.

In another embodiment, set forth in Figure 11, the reduced pressure cell 13" fully encapsulates the thermoelectric generator 10 and photovoltaic cell 30. In this embodiment, junction surface 12 thermally connects to the environment via radiative heat transfer only. This thermal connectivity enables the amount of heat provided to the thermoelectric generator 10 during nighttime usage or removed therefrom during daytime usage, to be controlled, particularly in extreme temperature conditions.

In Figure 12, the reduced pressure cell 13' (as shown in Figures 9 and 10) further comprises an aperture or window 60. This enables the junction surface 11 usage to also serve as a sink during daytime usage. If the thermoelectric generator 62 uses the daytime sky as a sink (normally shielded from the direct rays of the sun) then junction surface 11 is

a sink in daylight usage and junction surface 12 is the source. Figure 21 further illustrates the window which forms the aperture 60 of the reduced pressure cell 13' to exchange radiative energy with a radiative source or sink. The radiative exchange area in the cell prefers line-of-sight contact with the sink (or source) energy exchange external body only, and hopefully no other bodies that will detrimentally influence the energy exchange. The size of the aperture can be larger, smaller, or substantially equivalent to the size of the radiative heat transfer area, with a size which maximizes the effectiveness of the radiative heat transfer area preferred.

To improve the radiative characteristics of the energy exchange, spectral transmitting characteristics of the window with the external body can be chosen accordingly. For example, when deep space is used as a sink, deep space at approximately 4°K is always visible to terrestrial objects in certain band widths. Rain, snow, clouds, etc., notwithstanding, there is always an energy exchange. Window optical properties will be selected to optimize this energy exchange. Coatings may also be applied to the window to augment or improve its energy transmitting capabilities. The internal surface of the window can be coated to maximize transmission from the radiative heat transfer area while minimizing the internal reflectivity. Also, when exclusively using thermoelectric generators and deep space as a sink, the external window surface may be coated with coatings that affect maximum reflectivity of all energy, with minimum transmission inward.

Alternatively, if the daytime usage will be exclusively thermoelectric generator elements that utilize the sun as a thermal source, then maximum transmissivity is desired through the external surface of the window. The optical properties of the window and the

surface coatings would preferably effect this result, with radiative energy bandwidths maximized.

In an alternative embodiment employing the thermoelectric generators and the photovoltaic cells in parallel arrangement exposed to the external surroundings of the window, the coatings which maximize the transmissivity of the energy needed to heat the hot junction of the thermoelectric generator elements is preferred. These coatings should also allow the transmittance of the solar radiation that excites the electrons in the photovoltaic cells into the conduction band to increase electron activity and improve electrical power generation.

It should be noted that if the daytime usage will be exclusively employing thermoelectric generator units which will utilize the sun as a thermal source, then maximum transmissivity in the solar thermal range (blocking deep space coating) is desired through the external surface of the window into the pod. The optical properties of the window and the surface coatings would effect this result, with appropriate radiative energy bandwidths maximized.

The appropriate coating to be applied to the interior and/or exterior surface of the window can readily be determined by an artisan, with coatings which would allow transmissivity for the atmosphere of about 8 μm to about 13 μm, preferred, although other bands are available and may be utilized to maximize the energy transfer.

The electric circuit of an embodiment of the nighttime solar cell is also shown in Figure 1. During nighttime periods, or periods without incident light, current 17 travels in the direction shown from junction surface 11 to current flow direction circuitry 20 via connection 18. Current flow direction circuitry determines the direction of the incoming

current 17, and properly orients the current into outgoing current 19 which is carried via connection 22 where it is stored or consumed by load 21.

Referring next to Figure 2, there is illustrated a schematic representation of an embodiment of the present invention during daylight operation. In addition to the embodiment previously described the nighttime solar cell illustrated includes a photovoltaic cell 30 comprising concentrating lens 31, n-type doped material 14, and p-type doped material 15. Photovoltaic cell 30 is arranged within thermoelectric generator 10. During daylight operation an embodiment of the present invention produces electrical energy from thermoelectric generator 10 as well as photovoltaic cell 30. Concentrating lens 31 receives solar energy 32 falling between junction surfaces 11 and focuses it upon n-type doped material 14 and p-type doped material 15. Thus configured photovoltaic cell 30 generates current 33, 34 which is carried to load 35, 36 via connections 37, 38.

The operation of a thermoelectric generator during daylight conditions is also illustrated in Figure 2. During daylight conditions thermoelectric generator 10 functions opposite to that described above for nighttime conditions. Solar energy 32 enters the device and warms junction surfaces 11. The irradiation of solar energy upon junction surface 11 causes the junction surfaces to become the hot junction and the relatively cooler ambient conditions cause junction surface 12 to become the cool junction surface for the thermoelectric generator. In a preferred embodiment, the absorptivity of surface junction 11 is greater than 0.90. In addition, for certain embodiments it is advantageous to select a material for surface junction 11 wherein the emissivity and the absorptivity are nearly equal. Electrical current 17 is generated by the temperature difference between the hot and cold junction surfaces and is opposite in direction to that produced during nighttime

operation. Current 17 is carried to current flow direction circuitry 20 wherein its direction is properly oriented into outgoing current 19 and carried to load 21 via connection 22 where it is either stored or consumed.

Alternatively the thermoelectric generator could be solely utilized, even during the day. In this operating mode, during the day, the thermoelectric generator would be shielded from the rays of the sun and allowed to look at deep space. This mode of operation is the same as the nighttime mode of operation, and the current flow direction sensing circuitry is not necessary, but the reduced pressure cell is preferred for improved operation.

Yet another mode of operation would be to expose the radiative heat transfer area to the direct rays of the sun so that it becomes the hot junction for the thermoelectric generators and the ambient environment (or some other sink) becomes the sink temperature for the waste heat. This mode of operation is opposite to the nighttime mode, therefore the current flow direction circuitry is employed.

Although the connections and loads illustrated in Figures 1 and 2 are shown as separate they may be combined and interconnected with other such devices as the electrical needs of a particular embodiment dictate. The embodiment shown in Figs. 1 and 2 may be terrestrial or space based. The important distinguishing characteristic between a terrestrial based application and a space application is the reduced pressure cell. The reduced pressure cell insulates the surface junction of the thermoelectric generator from the earth's ambient surroundings while simultaneously allowing for the surface junction to react radiatively with the sun or the night sky. In space based applications the insulative properties of the reduced pressure cell are not necessary.

Referring now to Figure 3 there is illustrated another embodiment of the present invention. This embodiment is configured for terrestrial use and includes, in addition to the embodiments previously described, thermally insulative material 40. Thermally insulative material 40 insulates photovoltaic cell 30 from thermoelectric generator 10. With the two devices thermally insulated the performance of the thermoelectric generator is not influenced by any thermal transfer from the photovoltaic cell, and the overall performance of the nighttime solar cell is enhanced. In addition the photovoltaic cell is not influenced by the thermoelectric generator. The embodiment shown in Figure 3 may also advantageously include a concentrating lens as previously described.

Referring next to Figure 4 there is illustrated another embodiment of the present invention. In the embodiment illustrated the photovoltaic cell 30 includes n-type 14 and p-type 15 materials connected in series with n-type 14 and p-type 15 materials of the thermoelectric generator 10 to yield a series thermoelectric-photovoltaic device 9. In this particular embodiment the charge carrier collection capability, or the current flow, of the device is greatly improved.

Illustrated in Figure 5 is still other embodiment of the present invention. The partial array 8 illustrated includes a pair of series thermoelectric-photovoltaic devices, heat transfer fins 41, and encapsulant 42. Heat transfer fins 41 are disposed in heat exchange relationship with junction surfaces 12 and the ambient air. During nighttime operation the heat transfer fins enhance the conduction of heat from the ambient air to the junction surfaces, and during daylight conditions the heat transfer fins improve the transfer of heat from the junction surfaces to the ambient air. Various heat transfer augmentation can be utilized such as forced air, water, another fluid, or a thermal source of waste heat for

nighttime operation and forced air, water, another fluid, or a thermal sink for daytime operation, among others, and combinations thereof. Furthermore, the heat transfer augmentation can be disposed on junction surface 11 and/or 12, external to the cell, or internal to the cell, i.e. in thermal communication with the reduced pressure cell 13,13',13", junction surface 11, and/or junction surface 12. Furthermore, the heat transfer augmentation can be used for units that are ganged or assembled in arrays or on panels and includes the use of a forced fluid in a conduit or pipe (e.g., see 41" in Figure 22) thermally attached to the pod, or of a waste stream that could add or remove energy from the units as required. Encapsulant 42, essentially a cover, is bonded to junction surfaces 11 under reduced pressure conditions to form reduced pressure cells 13.

Further embodiments of the present invention are illustrated in Figures 12 - 18 which illustrate some of the possible variations, both relative size and geometry, of the thermal junctions 11, 12 and/or the p-type 15 and n-type 14 materials. In Figure 12, junction surface 11 has a larger surface area than junction surface 12, with a thermoelectric generator disposed therebetween accordingly. Figure 13, which does not show the reduced pressure cell for clarity, illustrates a thermoelectric generator coupled with a photovoltaic cell 64 in a parallel fashion. The junction surface 11 extends over the n-type and p-type material with the radiative area for the thermoelectric generator greater than the area for the photovoltaic cell 64. This embodiment allows for parallel power generation using both the thermoelectric generator and photovoltaic cell, allowing for higher daytime temperature operation of the thermoelectric generator without detrimentally impacting the operation of the photovoltaic cell.

Referring to Figures 14 and 14A, which illustrates a cascaded thermoelectric generator with the larger junction surface 11 exposed to the radiative aperture 60, and an additional, optional radiation heat transfer area 5. The radiation heat transfer area 5 which is another heat transfer plate similar to and thermal conductively connected to junction surface 11, can be sized to increase or decrease the amount of energy radiated external to the cell to improve the overall operation of the electric power generator; e.g. it can be as small as the surface area of the small junction surface or as large as the aperture opening to provide the greatest flexibility of area variation to control the energy that the module can exchange radiatively through the aperture 60. Sizing of the radiation heat transfer area can be a ratio (larger or smaller) than the cross-sectional area of the sum of the thermoelectric generator elements in a single tier or of the other surface area exposed thermally to the exterior of the reduced pressure cell. As with the junction surface, the radiative heat transfer area can be a thermally conductive material including metals such as copper, aluminum, combinations thereof and others.

The use of the cascading arrangement increases the length of the thermoelectric generator elements and the thermal resistance of the module, thereby allowing increased power output. The performance of thermoelectric generator is dependant on the temperature differential across the module. By increasing the length of the module p-n materials, the temperature differential increases. This length increase can be used to optimize (maximize) the power output from the unit. Increasing the length of the p-n material can result from unique cascading designs as shown in various embodiments of this patent. Numerous other geometries can also be used to increase the thermal resistance of the p-type and n-type materials, including a coiled geometry; a long, slender geometry,

unique cascading, element snaking, and element stacking geometry, among others and combinations thereof, as well as various p-type and n-type material orientations, including, but not limited to, parallel, perpendicular, 30°, 45°, 60°, or some other angle.

For example, Figure 15 illustrates long, slender p-type 15 and n-type 14 materials used in conjunction with a mechanical support 68 for providing structural integrity to the materials 14, 15, wherein the ratio of the length of the p-type 15 and n-type 14 materials to the area thereof is preferably about 4 or greater, with about 5 or greater especially preferred. The mechanical support 68 employed herein, which can be a single or multiple sectioned support and which is preferably additionally a thermal and electrical insulator, enables static support of the junction surfaces 11, 12, as well as for dynamic applications of the reduced pressure vessel, and improved structural integrity of the p-type 15 and n-type 14 materials. Possible mechanical supports 68 can be composed of a thermally insulating material capable of maintaining the distance between the junction surfaces 11, 12. The size and geometry of the mechanical support 68 should be sufficient to provide the necessary structural integrity to the p-type 15 and n-type 14 materials.

Figure 16 illustrates that the length of the p-n elements can be extended significantly when put into the reduced pressure vessel. In this embodiment, the thermal conductors 66, which are typically composed of a metallic or semiconductor material, are transition pieces which allow the semiconductor materials to be installed in a perpendicular orientation (or some other angle) to the original p-n material. In this way, several "layers" of p-n material can be added without increasing the distance between the hot and cold junctions of the module, while at the same time increasing the thermal resistance of the module. Since the temperature differences between the different material

sections are small enough and due to the employment of the reduced pressure vessel, the mode of heat transfer, radiation, between the material sections is rendered insignificant. Consequently, such an arrangement of p-n materials is possible without adversely effecting the power output of the system.

Furthermore, since matching the temperature differential to the operating range of the p-type and n-type material improves output of the p-n junction, as is shown in Figure 16 (p_1 and p_2), the p-type and n-type materials can be selected for the different "legs" of the layers that operate in a temperature range that is best suited for the temperature differential which that particular material will experience in that portion of the unit.

It should be noted that the increased thermal resistance provided by a design such as in Figure 16, can eliminate, for certain applications, the need for the reduced pressure cell. Although the vacuum pod or cell provides the ideal environment for insulation between the stacked or layered p-n materials, under certain conditions the layered module can operate without the benefit of the vacuum. For example, in a system operating in the 400°K to 600°K temperature range, although not limited to this range, atmospheric air (or some other gas) could provide adequate insulation between layers. Radiative heat transfer effects would be negligible in this low temperature range and the system would function well. Air circulation through the module would also improve performance. Even a mechanical insulation could be provided to ensure heat transfer through the p-n materials and not between the material stacks. In certain applications the vacuum cell may not be rugged enough to maintain the vacuum. Therefore, this particular embodiment of the present patent applies.

Figure 16 also shows an embodiment of the invention where surface 5 can be connected thermally to the surroundings by conduction heat transfer, eliminating the need for a window or aperture. Again this is one of the many configurations allowed by the flexibility of the present invention.

Figure 16A illustrates one simple scheme of how the p-type 15 and n-type 14 materials can be oriented with respect to one-another and the thermal conductors 66. Meanwhile, Figure 16B illustrates another orientation scheme using the reduced pressure vessel 13′ where the length of the p-type 15 and n-type 14 materials can be extended significantly using thermal conductors 66 to transition the materials. Numerous other orientations can be envisioned and are within the scope of the present invention. For example, in Figure 16B the initial vertical p-type material up to the thermal conductor 66 could have a cross-sectional area twice that of the two perpendicular p-type materials to maintain balanced thermal and electrical energy flows. Furthermore, as with other of these designs, several "layers" of p-type and n-type material can be added to form an array. It should be noted that in addition to the thermal conductors 66, insulators can also be employed, such as in area 70,70', to improve mechanical integrity.

In addition to geometry alternatives, the metallic conductors increase the thermal resistance, providing a greater temperature differential for the module to operate in, thereby increasing the power output. Consequently, the metallic conductors should be capable of increasing thermal resistance without adversely affecting the electrical properties at the electrical connections between the p-n material and the metallic conductors. Possible metallic conductors include copper, gold, aluminum, and silver, among others.

Embodiments employing metallic conductors are illustrated in Figures 14A, 16, 16A, and 16B. In Figure 14A, which is a variation of the cascading illustrated in Figure 14, thermal conductors 66 connect similar materials (e.g. p-type materials).

Design of the thermoelectric generator focuses upon obtaining a stable, maximum temperature differential in the operating range of the thermoelectric generator. Factors effecting the design of the module include the thermal conductivity and geometric specifications of cross-sectional area, and length of the p-type and n-type material elements. The geometry, in conjunction with the thermal conductivity, influence the thermal resistance of each element, which, in turn, determines the temperature differential between the hot and cold junctions.

Alternatively, as is illustrated in Figure 17, the semiconductor material (p-type material) can be a continuous medium without metallic conductors to interrupt the perpendicular transition. Here the p-n materials "snake" the full distance from the hot junction to the cold junction (or vice versa) such that the thermal resistance is entailed throughout the entire semiconductor material. The added material can be utilized to increase the electrical power output of the module. Mechanical support of the snaked legs of the p-n material can be added to improve the structural integrity of the module.

Optionally, the p-n element could be drawn through a wire die (or by some other means) to manufacture the thermoelectric generator elements as a long thin wire. Coating the wire with insulation, then coiling the element into a small mass to fit into the vacuum pod would improve both thermal and electrical properties and characteristics of the module.

In Figure 18, the p-type and n-type materials reside on thin film insulators which enable the construction of light weight modules. In this embodiment, thin film technology is employed to manufacture the p-type and n-type materials by the deposition of the semiconductor on thin film insulators that can be installed into the reduced pressure cell. This enables further snaking the p-n elements, laterally, longitudinally and otherwise, to increase the thermal resistance of the system and improve the cross-sectional area of the semiconductor material, hence improving the power generating capabilities of the vacuum pod. Various types of thin film insulators can be employed, such as those having sufficient thermal insulation to inhibit adverse thermal effects between the elements. Possible insulators include glass, ceramic, thermoplastics, and thermoset materials, among others, combinations and composites thereof. The thickness of these films should be sufficient to attain the desired insulating effects, with a thickness up to about 30 mils or greater typically sufficient, below about 20 mils preferred, and up to about 10 mils especially preferred.

Figure 19 shows individual reduced pressure units 80 ganged into an array 84 to improve the power producing capability of the units and produce the electrical output characteristics desired. These units can be designed to have side-by-side plug-in assemblies with series or parallel electrical connections as well as end-to-end plug-in assemblies, e.g. similar to Lego™ or Erector Set ™ modules with plug-in capabilities. The vacuum pods could also have electrical connections that come out of the bottom to assemble the modules on a buss or can be manufactured as a gang of units that are connected electrically and evacuated as a single unit but sealed as individual cells. Again, there is no restriction on the size of the vacuum pod or the number of modules inside.

Consequently, various units can be connected electrically to produce a desired voltage and current as required for the application of the power generating unit. In practice, to ensure that a majority of the vacuum pods maintain their vacuum, hence their maximum power producing capability, smaller pods, interconnected electrically but isolated mechanically (i.e., small chambers), are desirable. Therefore the unit shown in Figure 19 can have individual chambers for vacuum purposes but be interconnected electrically. Obviously the vacuum chamber can be as large as desired.

Figure 20 demonstrates an embodiment of the present invention as part of an assembly to increase the power producing capability of an area dedicated to producing power from a renewable source. Daytime utilization of the area produces electrical energy from a solar panel, with or without thermoelectric generators as part of the energy producing medium. For nighttime utilization of the area, the panel is rotated to expose the opposite side of the panel to the nighttime sky and produce electrical energy from the vacuum pods with thermoelectric generators. In this way, more of the available energy producing area can use the thermoelectric generators exclusively at night when the photovoltaic cells are ineffective. There are many schemes that can be incorporated in combining the cells back-to-back in this mode to allow the circulation of air, water, or other fluids of thermal capability (cooling or heating) to augment and enhance the power producing capability of the panel.

Referring next to Figures 6 and 7 there is illustrated an array of the thermoelectric-photovoltaic device of the present invention. In this embodiment there are included support rails fixedly attached to array 8. This embodiment is particularly suited for electrical power generation in connection with a device in a low-earth orbit. With the

support rail disposed as illustrated the array would be oriented such that surface junction 12 would be the hot junction and junction surface 11 would be the cold junction. Because the ambient atmosphere of space has a reduced atmosphere, this embodiment would not require the reduced pressure cell. A similar support structure could be envisioned for mounting the array from the opposite side.

Referring finally to Figure 8 there is illustrated a satellite 50 employing an embodiment of the present invention. Satellite 50 is illustrated in a low orbit about earth 51 including panel arrays 8 positioned about its exterior. The array panels are oriented such that there is always a hot side of the array and a cold side of the array. For example at position I as depicted in Figure 8 the hot side of the thermoelectric generator and the photovoltaic cells are facing the sun 52. In position I the thermoelectric-photovoltaic array is producing electrical energy to power the satellite from both the thermoelectric generator as well as the photovoltaic cells. In positions II and IV a portion of arrays 8 are shadowed by the earth and a portion are in direct sunlight. In these positions the photovoltaic cells in sunlight are producing energy while the photovoltaic cells in the shadow of the earth are not. At the same time the thermoelectric generators in sunlight are producing energy by absorbing solar radiation and emitting heat to the ambient atmosphere while the thermoelectric generators in the shadow of the earth are absorbing heat from the ambient atmosphere and emitting heat to black sky. In position III all of the arrays are in the shadow of the earth while the backside of the arrays are facing deep space. In this position the photovoltaic cells are not functioning to produce energy. The thermoelectric generators are producing electrical energy by absorbing heat from the ambient atmosphere and emitting heat to deep space.

The thermoelectric-photovoltaic device of the present invention solves many of the problems of the prior art. In a terrestrial setting during nighttime conditions the reduced pressure cells surrounding the cold junction surfaces of the thermoelectric generator enhance the heat transfer relationship between the device and the black sky thereby increasing the effectiveness of the device and utilizing the surface area of the device to produce energy at night. During daylight terrestrial operation the device combines photovoltaic cells with thermoelectric generator cells in a staged fashion such that the full surface area of the cell is exposed to sunlight and thermal energy to produce electrical energy. By contrast U.S. Patent No. 4,710,588 discloses a solar cell in combination with a thermoelectric generator in a series fashion. Because of the series arrangement of the elements the thermoelectric generator cannot effectively absorb thermal energy from the sun during daylight conditions and cannot effectively emit heat to black sky at night. In addition, the basic design of the current invention takes advantage of current state of the art manufacturing techniques using thin film and/or transparent electrical connectors with thin film semiconductor materials.

The embodiments of the present invention set forth feature basic p-type material and n-type material junctions. Embodiments of the inventions do include other configurations including cascading or staging of the materials to improve the efficiency. In addition, the particular type of material for various embodiments includes those known in the art as well as those yet to be developed. For example, most photovoltaic cells in use today employ monocrystalline and polycrystalline silicon. However, more expensive compound semiconductors such as GaAs, InP, and CdTe as well as various ternary and quaternary compounds such as AlGaAs or GaAsInP have shown promise for photovoltaic

thermoelectric generator cascading then provides the element area ratio with the radiative area that includes a factor or constant that improves the thermal resistance. Increasing the thermal resistance of the p-n materials increases the temperature differential between the hot and cold junctions of the thermoelectric generators, improving the thermoelectric generator's power producing capability. This can also be accomplished utilizing unique cascading schemes that increase the length of the p-n elements. Alternatively, lengthening the thermal path can be accomplished by introducing horizontal (or some other angle) flow paths of the thermoelectric generator elements with offset hot and cold plates. The elements can be snaked up and down or back and forth for a series of convolutions to increase the thermal resistance between the hot and cold junctions of any pair. If the increased length takes place in the horizontal direction, many more embodiments of the patent can be envisioned. It should be noted that increased thermal path, while increasing the temperature differential, does affect electrical performance of the module. By controlling the thermal path, however, more options are available for geometric design to improve electrical output.

As has been previously stated, performance of a thermoelectric generator is a function of temperature differential and the stability thereof. The present invention employs stable thermal sinks and sources, for example, the black sky and the surrounding air, with other sources and sinks possible. With respect to the temperature differential, a maximum temperature differential in the operating range of the p-type and n-type materials is preferred. The units are designed to enable a controlled temperature drop which will determine the temperature differential.

cell applications. With respect to materials for the manufacture of thermoelectric generators materials such as Bi_2Te_3, PbTe, or PbSnTe, among others and mixtures and alloys thereof, are quite suitable.

The thermoelectric-photovoltaic units of the present invention can employ a reduced pressure cell around part or the entire thermoelectric-photovoltaic unit. The reduced pressure cell insulates the cold junction from the ambient temperature, providing excellent insulation of the cold junction from the surroundings, while at the same time, allowing the cold junction to "see" the black sky and exchange energy with it by radiation heat transfer. Similarly, during daytime operation of the system, the reduced pressure cell insulates the hot junction of the module, now heated by the sun, from the cool ambient air, improving the power generating capability of the module.

The present invention further improves the performance (increases the electrical power output) of the unit by adjusting the geometry and/or size of the p-type and n-type materials to increase their thermal conductive resistivity. For example, the materials of the present invention have a preferred length to cross-sectional area ratio of about 4 or greater, with about 5 or greater especially preferred. At these ratios, it may be preferable to employ support to improve structural integrity of the materials. Consequently, supports can be employed, such as disposing insulation columns parallel to the individual thermoelectric elements to improve rigidity and cell durability, while not providing a thermal link between the two junctions.

Performance improvement is also realized. In one preferred embodiment, various configurations of thermoelectric generator cascading can be utilized to improve overall cell performance when compared to a single row of elements which has no cascading. The

A further advantage of the present invention is that the unit is capable of radiating thermal energy from any standard thermodynamic cycle into deep space, thus "dumping" waste energy away from the environment of the earth into outer space. For example, in a large power plant that operates on the Rankine Cycle, there is a large amount of waste thermal energy that enters the environment. This is such a large amount of energy (on the order of 100's of kilowatts) that the pod array may be too large to be practical. But in rural applications where stirling cycle engines can pump water for domestic use or irrigation, the vacuum pod may be usable. The vacuum pod could lower the overall operating temperature of the unit and/or improve cycle efficiency. This embodiment of the present invention is shown in Figure 22.

Yet another advantage relates to the parallel operation of the device. Increased operating temperature of the photovoltaic cell reduces the performance, hence the power producing capability, of the device. In the series operation of the prior art device, the photovoltaic cell must become very hot for the thermoelectric generator to perform adequately. The higher the operating temperature differential of the thermoelectric generator, the better the performance. However, this high operating temperature is detrimental to the performance of the photovoltaic cell. To prevent the photovoltaic cell from becoming too warm, the operating temperature of the thermoelectric generator must be reduced, to maintain good performance of the photovoltaic cell, therefore, there are two opposing physical phenomena that must be balanced to try to operate the device. In the present invention, these two physical phenomena can be optimized for maximum performance of the photovoltaic cell as well as the thermoelectric generator. Referring to Figure 9, for example, the p-n element in the center of the device is the photovoltaic cell

30' which is thermally insulated from the surrounding thermoelectric generator. Therefore, in this embodiment, the photovoltaic cell 30' and the thermoelectric generator are insulated from each other to enhance performance. To further improve the efficiency of the photovoltaic cell 30', it may optionally be connected to the cold junction surface, shown as junction surface 12, via a thermal connector 2.

Furthermore, the surface of junction 11 can be designed to maximize the temperature of the junction, independent of the temperature of the photovoltaic cell. In a low earth orbit application, while facing the sun, the combined parallel operation of the thermoelectric generator and photovoltaic cell produces a higher density of charge carriers, hence an increased flow of electrical current, for operating the electrical devices on the satellite, without the thermal restriction placed on the device by prior art designs.

It should be noted that the perpendicular orientation or horizontal assembly of thermoelectric generator p-type and n-type materials, as well as the "snaking" of the p-type and n-type materials, is not restricted to the unique design utilized and taught herein. The technique of perpendicular elements and of "stacking" of p-type and n-type materials of different thermal and electrical properties to better match the natural temperature range differentials that will occur, can be used in any module construction, improving the power generating performance of the unit tremendously.

The energy generating device of this invention teaches: (1) using the reduced pressure cell to improve thermal insulation between the thermoelectric generators and the photovoltaic cells as well as between the various p-n elements of the thermoelectric generators and their hot and cold junctions as well as the p-n elements with the surroundings and/or the ambient; (2) the area ratios between the hot and cold junction

plates as well as the thermoelectric generator element areas can be augmented to improve system performance; (3) various cascading schemes and module designs (including lengthening of the thermoelectric generator elements) to improve temperature differentials between the hot and cold junctions, improving the power producing capability of the vacuum pods; (4) improved overall strength between the hot and cold junction support plates, allowing for thinner, longer p-n elements; (5) perpendicular or parallel (or any other angle) p-n elements with added length to improve power generating capabilities; (6) manufacturing the configuration of the p-n elements in a fashion that allows "snaking" of the elements to increase temperature differentials; (7) using thin film and thin film semiconductor materials, for the thermoelectric generator's capability of increased temperature differential operation; (8) the combination of a power panel with the vacuum pod array construction back-to-back with a photovoltaic cell array will <u>increase significantly</u> the electrical power output of a given panel area, tremendously improving the state of the art of electrical energy production possible from a given area; (9) the improved spectral properties of the aperture window to enhance the operation of the vacuum pod.

Referring back to Figure 10 a schematic view is shown of the thermoelectric-photovoltaic power generating device. The photovoltaic cells and the thermoelectric generators 15 are connected in parallel to view the ambient sky simultaneously. Several operating modes can be utilized depending on the configuration of the cell as discussed above. In Figure 12 a thermoelectric generator module 62 only is shown. Photovoltaic cells are not a part of the system so the cold junction plate 11 covers the entire top surface of the cell 13′ exposed to the atmosphere. The nighttime solar cell, functioning with the thermoelectric generators 62 absorbs thermal energy from the surroundings at the hot

junction plate 12, transfers the energy through the thermoelectric generator elements 14 and 15 to produce electric power, then rejects the energy to deep space. For particular designs and applications, the vacuum cell 13′ improves the operation of the device.

Figure 23 shows one embodiment of the present invention. In this embodiment cold junction plate 100, encapsulated by a vacuum cell 104, serves as a direct heat transfer link between the ambient surroundings and deep space. The cold junction plate 100 now serves as strictly an anti-global warming device without the added benefit of electric energy production. The radiant heat transfer surface 102 of the cold plate facing deep space would ideally be a blackbody emitter with an emissivity of one. In this way, as discussed previously, all the transmission bands in the infrared spectrum that are transparent through the atmosphere to deep space will allow the maximum of energy transmission by radiation.

Figure 24 shows the anti-global warming device without optional vacuum cell; 104 and Figure 25 illustrates the device in its simplest form as an isometric view.

The design of the anti-global warming plate can be modified in many ways to augment or improve the amount of heat that the device absorbs from the ambient and transfers to deep space. Figure 26 shows the plate with four "feet" 106 on the bottom 105 to lift the cooler off the support surface and provide better heat exchange with the surrounding air.

The cooler in Figure 27 has heat transfer fins 108 on the bottom to improve heat transfer with the ambient. Obviously many more configurations of the device can be utilized to improve the heat exchange with the surroundings. These are but a few

examples to show the many designs that are available without putting any restrictions on the scope of the present invention.

Figure 28 illustrates another embodiment of the invention. In this figure, the cooler is used to cool or remove heat from a thermal polluter such as an automobile engine that is cooling down after being driven. Now, the cooler device takes the form of a "blanket" 110 that covers the hood 112 of an automobile 114 as it cools. Instead of all the thermal energy from the automobile engine entering the atmosphere, through use of the blanket 110, a percentage is transferred directly to deep space, thereby reducing the thermal load on the atmosphere.

Actual use of the blanket 110 is simple. After the car is driven and parked, the driver may place the spectral blanket 110 on the hood 112 of the car. When the engine has cooled down, the blanket 110 can be removed. Depending on the spectral properties of the blanket spectral surface 102 facing deep space, the blanket 110 can be used day and night, or only at night. Obviously the surface of the thermal blanket 110 is designed to have the optimal spectral characteristics of the anti-global warming device.

Figure 29 of the present application shows the hood 112 of the automobile 114 designed specifically at the factory to have the radiative thermal properties of the anti-global warming cooler 116. This hood 112 must be designed with the commitment of the automobile manufacturers to help alleviate the problem of global warming.

Figure 30 shows the usage of the earth cooler device 118 on the surface of a grill exhaust fan unit 120 at a fast food restaurant. Here the thermal cooler 118 radiates directly to deep space a portion of the thermal pollution that would enter the atmosphere. In such installations, the exhaust system 120 can be designed on the roof of the restaurant 122 with

a larger surface area to facilitate the transmission of waste heat from the cooking system to deep space. In this application of the present device, the radiative properties should have a high emissivity for nighttime radiation to deep space with a low absorptivity when solar energy will heat the exhaust system. In effect the grill exhaust surface would continue to transmit thermal energy to deep space while absorbing little thermal energy from the sun. Obviously this surface can be mechanically "rotated" to best match time of day operation. An alternate design to increase daytime transmission of thermal energy to deep space would be in the original building construction which can aid in reducing thermal emissions. The grill roof structure can be designed so that a major portion of the heated surface is in the shadow of the building, shielding the spectral surface from the rays of the sun.

Figure 31 illustrates another practical use of the present device for graduating high school or college students. The top of the head is considered to be the predominant part of the human anatomy for transferring heat to the environment. Therefore the graduates' mortar boards 124 can be designed with a spectral surface 102 on top.

As previously discussed, Figure 32 shows the anti-global warming device plate 100 on a fence post 126 to transmit thermal energy to deep space. The projected cross-section of the area covered by the plate 100 would have an effective emissivity of about 0.3, well below the emissivity of the anti-global warming plate 100. Note, the fence post could easily be a piece of lawn furniture, a picnic table or a cardboard box set out in the grass, all with a clear view of the sky. Again the spectral properties of the terrestrial item covered by the present device would not be as favorable as those of the cooler for transmitting thermal energy to deep space, hence the cooling of the ambient.

The basic operation and design of the anti-global warming device remain unchanged for different uses. However, the application of the device can vary in two ways: (1) waste thermal heat can be removed from the surrounding atmosphere by strategically placing a cooler on any surface that does not have the emissivity or radiative properties required to effect heat transmission to deep space; or (2) waste thermal heat can be removed directly from thermal polluters utilizing the "blanket" cooler of the present invention or utilizing the device designed for thermal systems that dump waste heat directly into the atmosphere (the restaurant grill example) without deep space cooling. Obviously, any industry can utilize this cooler.

Those skilled in the art and familiar with the movement of infrared energy through the atmosphere and the spectral bands that are transparent to this energy will appreciate the usefulness and efficacy of the anti-global warming device. Although there are many material combinations that can be utilized to produce this terrestrial cooling effect, the teaching of the art of anti-global warming does not restrict in any way the use of only the materials in this application. These are considered to be examples only of what can be achieved, and are not meant in any way to restrict to what is taught here. For example, as shown in Figure 34, another example of the present device may be a transmitting material 128 utilized on an outdoor electric light 130. The heat generated by the outdoor light adds to thermal pollution. With the device intimately designed into the case of the light, a very large percentage of the thermal pollution will leave the atmosphere and go directly into deep space. The spectral properties of the cooler surface as taught herein and the surface area can be selected so that most of the waste energy will go into deep space.

Finally, even a modified Frisbee™ disc 134, as shown in Figure 33, can be used by day for throwing and whatever, then at night be left out with the spectral surface 132 radiating thermal pollution to deep space.

The simplicity of the drawings has been utilized to emphasize the salient points of the invention and in no way should be construed as a means to circumvent the nature or spirit of what is being claimed.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustration and not limitation.

What is claimed is: